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R. S. Kanwar
Iowa State University, rskanwar@iastate.edu

D. L. Karlen
U.S. Department of Agriculture, doug.karlen@ars.usda.gov

C. A. Cambardella
U.S. Department of Agriculture

C. Pederson
Iowa State University, carl@iastate.edu

CROP ROTATION EFFECTS ON NO_3-N LEACHING AND CORN YIELDS UNDER MANURE MANAGEMENT PRACTICES

R.S. Kanwar, Professor of Agricultural and Biosystems Engineering
D.L. Karlen, Soil Scientist, USDA-ARS NSTL
C.A. Cambardella, Soil Scientist, USDA-ARS NSTL
C. Pederson, Research Associate in Agricultural & Biosystems Engineering
Iowa State University, Ames, Iowa 50011

Introduction

Nonpoint source nutrient pollution is recognized as an important environmental and social issue for several reasons. First, manure from swine production facilities can have serious impacts on the quality of surface and ground water resources. Second, several states are in the process of creating laws to reduce nitrogen and phosphorus loadings from manure to soil and water resources. Third, pollution of water resources from nutrients supplied by manure to croplands will set parameters for developing public policies on the management of manure.

Swine production in the US has changed significantly in recent years. Today's animal production systems are becoming larger, and the public is concerned about the impacts of animal production facilities on surface and groundwater quality. Of particular concern are surface runoff losses of N in the forms of NH_4-N, NO_3-N and organic-N, and phosphorus (P) as phosphate-phosphorus (PO_4-P) and organic-P, and leaching losses of NO_3-N, PO_4-P, and bacteria to ground water. The NH_4-N at concentrations of > 2.0 mg/L can result in fish-kills, NO_3-N has a drinking water standard of 10 mg/L, and PO_4-P at levels as low as 0.05 mg/L can promote the growth of algae and speed up the process of eutrophication in lakes and reservoirs. Organic forms of N and P can reduce oxygen levels in surface water resources and further "enrich" the supply of nutrients causing nuisance aquatic plant growth. This can happen close to the source, or as far away as the Gulf of Mexico, where a "hypoxia zone" is drawing national and international attention. Another water quality issue is the potential of pathogenic bacteria being transported from the land receiving animal manure to drinking water sources.

Rapid growth in the size of swine production facilities in Iowa has resulted in a steady increase in animal waste production, with manure production ranging from 1 to 10 kg/day/hog depending on the hog's size, type and ration. Currently, 28.4 million tons of liquid swine manure is gathered in pits annually in Iowa (Midwest Plan Service, 1993; Iowa Agricultural Statistics, 1996). This situation has left no option for farmers but to apply more swine manure on agricultural lands. Continuous application of manure at higher rates to a field over a longer duration may result in the accumulation of more nutrients in the root zone than crops may need. Some nutrients, especially nitrogen in the form of nitrate is highly mobile and may leach to groundwater or to the tile drainage network. Gupta et al. (1997) investigated the effects of liquid swine manure on the quality of surface runoff. They reported that the total N, total P, NH_4-N and NO_3-N concentrations were lower in runoff generated from disk tillage plots, compared to that from the no-till plots. Jongbloed and Lenis (1998) reported that negative effects of swine production on the environment have already led to new legislation that limits the use of animal manure or the expansion or localization of pig operations in some countries. Nitrate contamination of groundwater is a major concern in hog-producing areas, and additional information on quantifying the impact of swine manure application on soil and water quality is needed (Gangbazo et al., 1997; Gupta et al., 1997; Kanwar et al., 1995).

Several other studies have been conducted in the USA and Canada to study the impact of swine manure on surface and groundwater contamination (Angle et al., 1993; Foran et al., 1993; Hockling et al., 1993; Kanwar et al., 1995). However, only limited field data are available in Iowa on the environmental effects of using swine manure as a source of nutrient (Kanwar et al., 1995, 1999). Kanwar et al. (1999) reported that six year (1993-98) average NO_3-N concentrations in the subsurface drain water from manure plots were 19.0 mg/L under continuous-corn and 14.2 mg/L under corn-soybean rotation. These results clearly show that application of swine manure to croplands can increase NO_3-N concentrations in the shallow groundwater at significantly higher levels. The objective of this study was to evaluate the potential of manure application on groundwater contamination and help in developing environmentally friendly manure management practices.

Materials and Methods

The study site was located at Iowa State University's Northeast Research Farm near Nashua, Iowa. Soils at the site are Floyd loam (fine-loamy, mixed, mesic aquic Hapludolls), Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls) and Readlyn loam (fine-loamy, mixed, mesic Aquic Hapludolls). These soils are moderately well to poorly drained and lie over loamy glacial till. This experimental site has 36, one-acre plots with fully documented tillage and cropping history for the past twenty years. In 1979, subsurface drains were installed to all these 36 plots at 95-ft spacing and approximately 4 ft deep. Each 195-ft x 225 ft plot has a drain along the center and along the north-south borders. A 30 ft grass strip isolated the plots on the east and west sides. Center drains were routed to sumps for monitoring subsurface drain flows while border drains isolated plots on the north and south sides. Each sump contained a sump pump with a flow meter. Flow meters are read manually three times per week. Data on flows was collected from approximately mid-March to the beginning of December each year. Water samples were collected from the sumps for NO_3-N analyses when flow meters are read three times a week. For water sample collection, subsurface drain sumps are equipped with a state-of-the art sampling system which pumps about 0.02% of the water discharged by the sump pump into the sampling bottle through the orifice tube installed on the sump discharge line (Kanwar et al., 1995; 1999). Sampling bottles are removed after they are filled with subsurface drain water. These bottles are immediately stored in the refrigerator at 4°C. The N in the water and soil was assessed using standard methods (APHA, 1995). Nitrate-nitrogen in water samples was analyzed spectrophotometrically using a Lachat Model AE ion analyzer. For soil samples, NO_3-N was extracted from soil using potassium chloride and analyzed using the Lachat Model AE ion analyzer. Data on corn yields was collected at harvest and was converted to 15.5% moisture content level.

Experimental treatments included reduced UAN fertilizer application to give N application rate of 100 lb/ac to corn plots grown in rotation with soybean and 120 lb/ac to continuous-corn under chisel plowing as the primary tillage practice. Alternate N-management strategies included the use of swine manure as the N source for both continuous-corn and corn-soybean rotation to give N application rate similar to UAN applications. Because of the difficulty in applying the desired N application rates from swine manure, the overall six-year average N application rates from swine manure were 145 and 120 lb/ac for continuous corn and corn-soybean rotation, respectively. Table 1 gives yearly variations in N application rates from liquid swine manure.

Results and Discussion

Achieving the desired N application rates with the liquid swine manure continued to be one of the most challenging tasks in this study. The difficulty in applying the intended rates of N with swine manure on an annual basis had some impact on the variability in NO_3-N concentrations in the tile water but six-year average application of N from manure was within 25 lb/ac in comparison with UAN plots.

Table 1 shows that average yearly NO_3-N concentrations in subsurface drain water in 1993 (first of the experiment) from corn plots ranged from 8.9 to 11.6 mg/l but showed no specific trends; which may reflect the effect of past management practices in these plots. The NO_3-N concentrations observed in 1993 from soybean plots were lower and ranged from 5.7 to 11.1 mg/l because no nitrogen was added to these plots in 1993. The NO_3-N concentrations in the manure plots rotated with soybean increased from 11.6 mg/l in 1993 to 18.2 mg/l in 1995. This large increase in NO_3-N concentration in the subsurface drain water was most likely due to higher manure application rates in 1994 and 1995.

Table 1 gives six-year average NO_3-N concentrations in the subsurface drainage water as a function of different N management systems. Highest six-year average NO_3-N concentration of 19.0 mg/l in the drainage water was observed from manure plots under continuous-corn production and the lowest average NO_3-N concentrations of 10.2 mg/l was observed from plots with UAN applications under corn-soybean rotation. Manure plots under corn-soybean rotation resulted in six average NO_3-N concentrations of 14.2 mg/l. These results indicate that the importance of corn-soybean production system in reducing NO_3-N concentrations in shallow groundwater.

Nitrate-nitrogen losses with subsurface drainage water were similar to drainage flow volumes observed for each plot. Generally, losses were greatest during 1993 due to higher precipitation and lesser during 1994 through 1998 when precipitation was near normal. However, six-year average NO_3-N losses were higher (23.1 lb/ac) under continuous-corn when compared with NO_3-N losses of 17.7 lb/ac under manure applications. Manure plots, under continuous-corn, showed the greatest NO_3-N loss which was most likely due to high application rate of manure during 1994 and 1995. Lowest NO_3-N loss of 12.2 lb/ac was obtained from plots receiving UAN applications under corn-soybean rotation.

Figure 1 gives six-year average monthly NO_3-N concentrations in subsurface drain water for various production system. Figures 1 (a) and 1 (c) show that monthly average NO_3-N concentrations in drain water from continuous-corn plots receiving swine manure were significantly higher for all months in comparison with corn plots rotated with soybeans. Similar results were observed for plots receiving UAN fertilizer (Figures 1). Figure 2 gives the six-year average cumulative subsurface drain flows and NO_3-N losses with drain water. This figure clearly shows that significantly higher NO_3-N leaching losses to subsurface drain water occurred from manure plots in comparison with UAN fertilizer applied plots.

Table 1 also gives yearly average corn yields for the six-year period. Three observations can be drawn from these data on corn yields. First, the lowest corn yields were obtained from continuous corn plots receiving either manure or UAN fertilizer. Second, highest corn yields were obtained from plots rotated with soybeans, which shows the importance of rotation. Finally, continuous-corn production results in highest NO_3-N losses and lowest corn yields.

Conclusions

This study resulted in the following two conclusions:

1. Continuous corn plots receiving N from swine manure resulted in significantly higher NO_3-N concentrations in subsurface drain water in comparison with manure plots rotated with soybean (Table 1 and Figure 1). The results of this study clearly indicate that the use of swine manure under corn-soybean rotation has the potential to reduce NO_3-N concentrations in subsurface drain water with proper manure management. Also, continuous-corn plots with manure applications resulted in the highest NO_3-N concentrations in the subsurface drain water in comparison with UAN fertilizer applied plots.

2. The highest corn yields were obtained from plots rotated with soybean under both manure and UAN fertilizer applications whereas, continuous-corn plots resulted in lowest yields.

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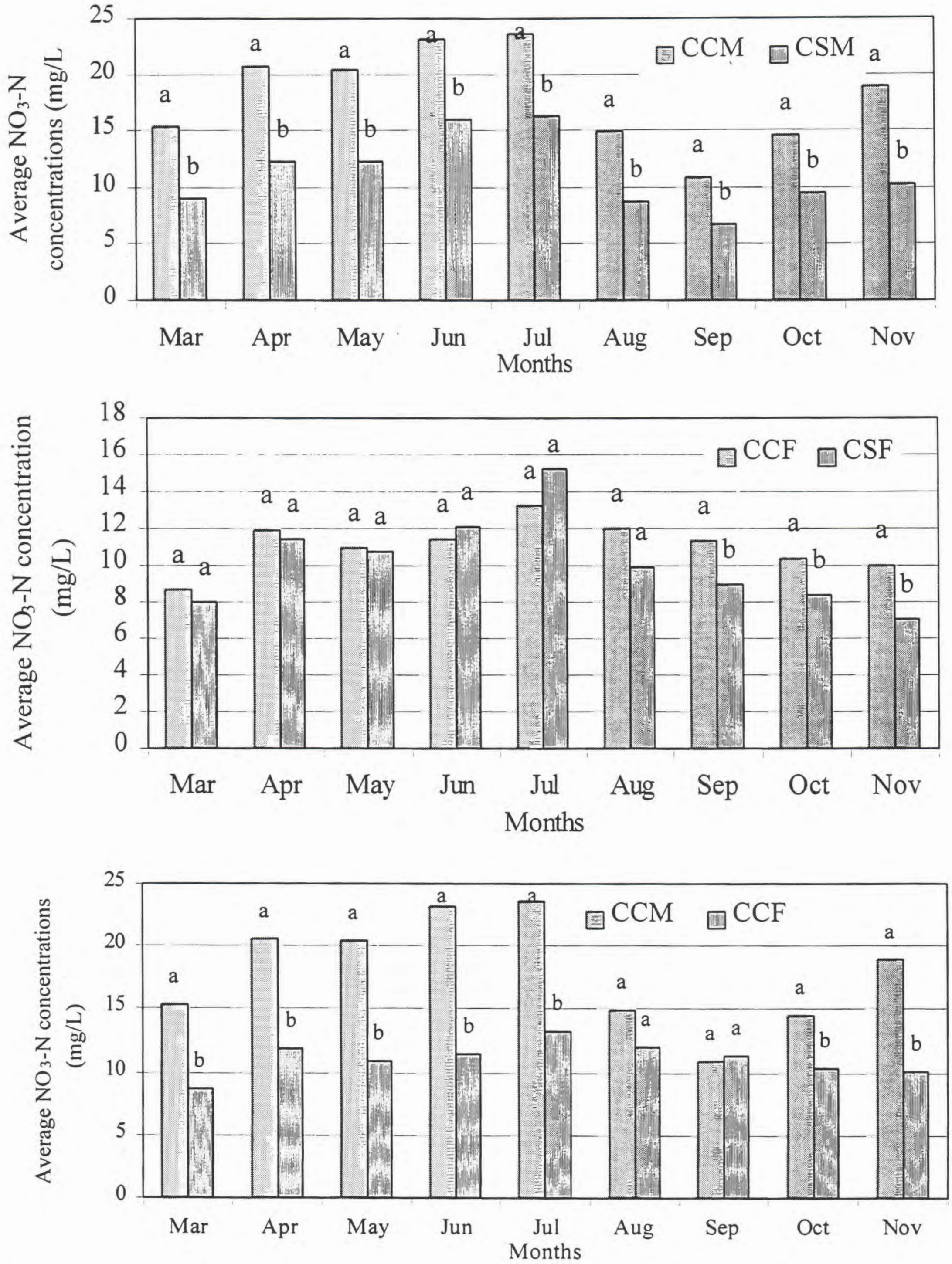
Table 1. Impact of swine manure and UAN-fertilizer applications on corn yields and yearly average NO_3-N concentrations and losses with subsurface drain water under continuous - corn and corn-soybean rotation.

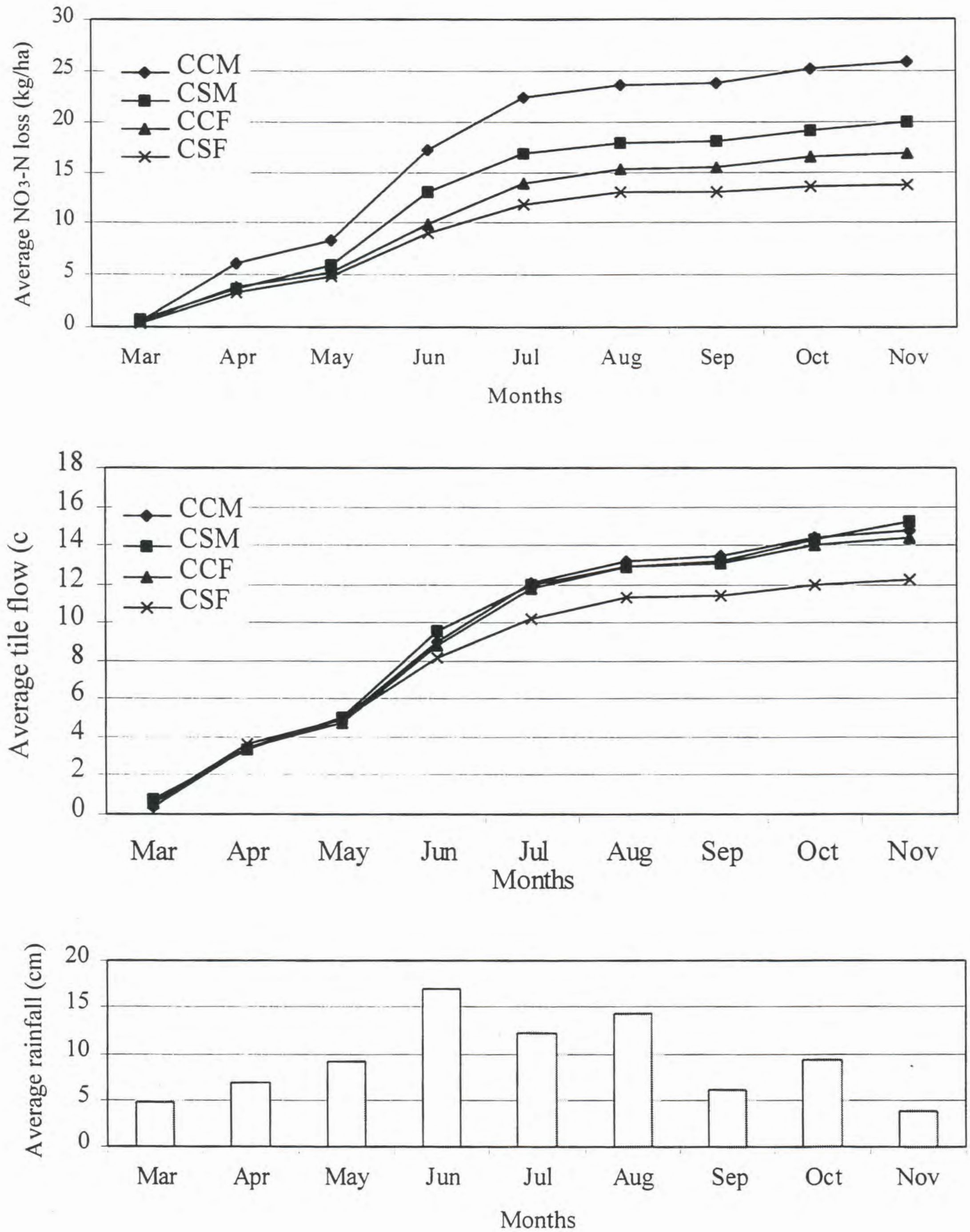
Year	Cropping systems	N-applications lb/ac	N-applications kg/ha	Avera-ge NO_3-N conc. (mg/L)	Average NO_3-N loss lb/ac	Average NO_3-N loss kg/ha	Corn grain yield bu/ac	Corn grain yield Mg/ha
1993	CC-Manure	61	68	11.1a	43.0a	48.3a	49c	3.1c
	CS-Manure	73	82	11.6a	31.4a	35.3a	100a	6.3a
	CC-Fertilizer	120	135	11.4a	41.6a	46.7a	73b	4.6b
	CS-Fertilizer	98	110	8.9b	29.2a	32.8a	81b	5.1b
1994	CC-Manure	233	262	18.0a	8.9a	10.1a	118b	7.4b
	CS-Manure	209	235	8.9b	10.6a	11.9a	134a	8.4a
	CC-Fertilizer	120	135	10.3b	6.9a	7.8a	92c	5.8c
	CS-Fertilizer	98	110	11.4b	2.4a	2.7a	126ab	7.9ab
1995	CC-Manure	269	302	31.9a	33.9a	38.1a	86c	5.4bc
	CS-Manure	194	218	18.2b	11.5b	12.9b	103a	6.5a
	CC-Fertilizer	120	135	14.4b	14.2b	15.9b	73c	4.6c
	CS-Fertilizer	98	110	15.5b	9.3b	10.5b	95ab	6.0ab
1996	CC-Manure	91	102	24.3a	101.a	11.3a	126b	7.9b
	CS-Manure	74	83	14.5b	11.3a	12.7a	137a	8.6a
	CC-Fertilizer	120	135	7.5c	3.3a	3.7a	111c	7.0c
	CS-Fertilizer	98	110	12.9b	5.6a	6.3a	140a	8.8a
1997	CC-Manure	92	103	12.2a	6.1a	6.8a	121	7.6c
	CS-Manure	76	85	11.2a	6.7a	7.5a	140b	8.8b
	CC-Fertilizer	120	135	9.3a	3.4a	3.8a	137b	8.6b
	CS-Fertilizer	98	110	12.5a	5.6a	6.3a	156a	9.8a
1998	CC-Manure	126	141	21.2a	36.3a	40.8a	115c	7.2c
	CS-Manure	94	106	14.5b	35.3a	39.6a	153a	9.6a
	CC-Fertilizer	120	135	12.9b	20.7a	23.3a	124b	7.8b
	CS-Fertilizer	98	110	12.7b	21.0a	23.6a	154a	9.7a
Six yearly average (1993-98)	CC-Manure	145	163	19.0a	23.1a	25.9a	102b	6.4b
	CS-Manure	120	135	14.2a	17.7a	19.9a	127a	8.0a
	CC-Fertilizer	120	135	11.1b	14.9a	16.8a	102b	6.4b
	CS-Fertilizer	98	110	10.2b	12.2b	13.7b	126a	7.9a

CC-Manure = continuous corn with liquid swine manure application
CS-Manure = corn after soybean with liquid swine manure application
CC-Fertilizer = continuous corn with UAN-fertilizer application
CS-Fertilizer = corn after soybean with UAN-fertilizer application



CCF= continuous corn with UAN-fertilizer; CSF= corn-soybean rotation with UAN-fertilizer
CCM= continuous corn with swine manure; CSM= corn-soybean rotation with swine manure

Figure 1. Six yearly monthly average NO_3-N concentrations in subsurface drain water as a function of crop rotation and N-management systems.



CCF= continuous corn with UAN-fertilizer; CSF= corn-soybean rotation with UAN-fertilizer
CCM= continuous corn with swine manure; CSM= corn-soybean rotation with swine manure

Figure 2. Six year average monthly rainfall and cumulative NO_3-N losses with Subsurface drain water.